# Enhanced Monitoring and Forecasting of South Asian Air Quality Episodes with Multi-Sensor Satellite Products and Dispersion Modeling

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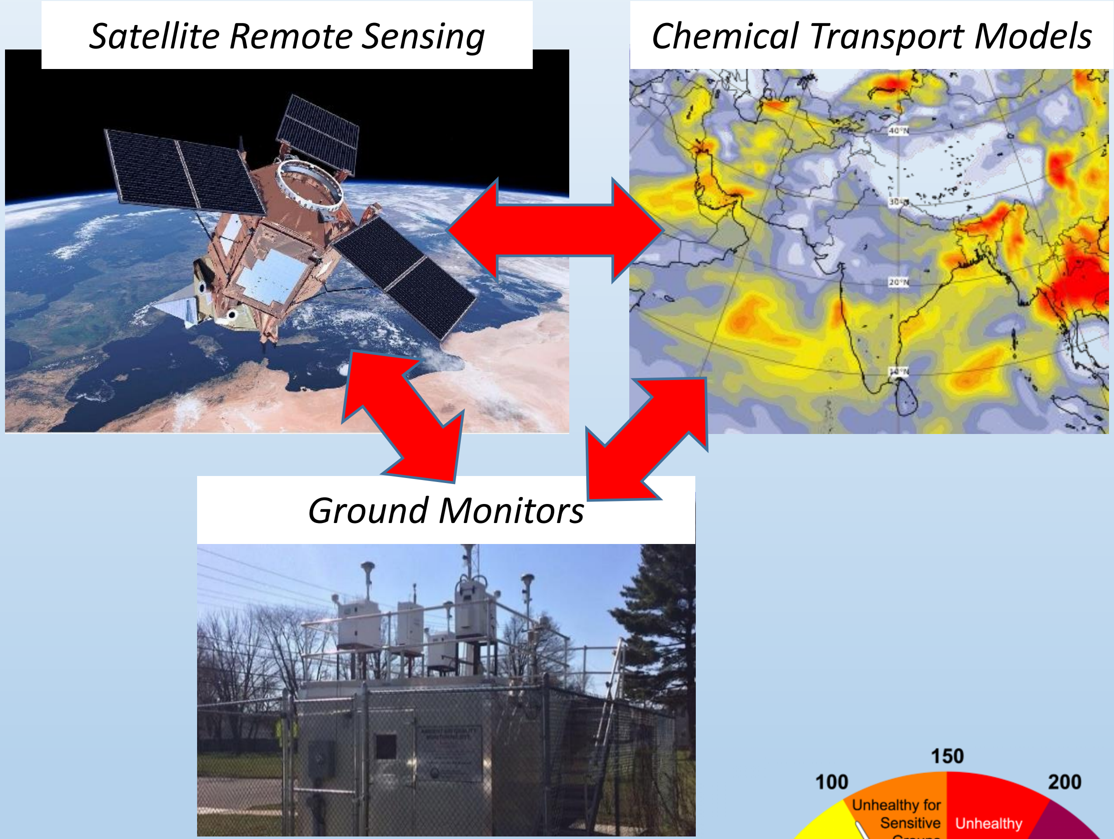
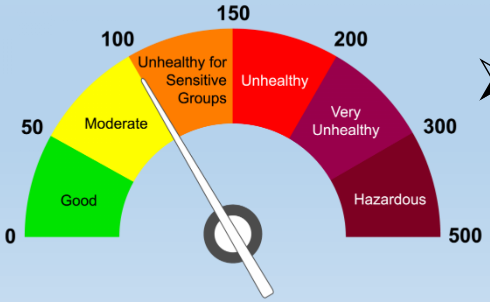
# Presentation Outline

- Project overview for air quality monitoring and forecasting over Hindu-Kush Himalaya (HKH) region of south-central Asia
  - ✓ *Enhanced monitoring with GEO-KOMPSAT-2A (GK2A), VIIRS/MODIS, and GEMS*
  - ✓ *Forecasting products with WRF-Chem and HYSPLIT dispersion*
- Application of classic, multi-spectral Red-Green-Blue (RGB) recipes to develop value-added air-quality satellite products over HKH
- Configuration of HYSPLIT for dust dispersion over HKH
  - ✓ *Significant dust episode during late March 2021*
  - ✓ *Inter-comparison of HYSPLIT simulations using different methodologies*

# Air Quality Monitoring & Forecasting Challenges in HKH

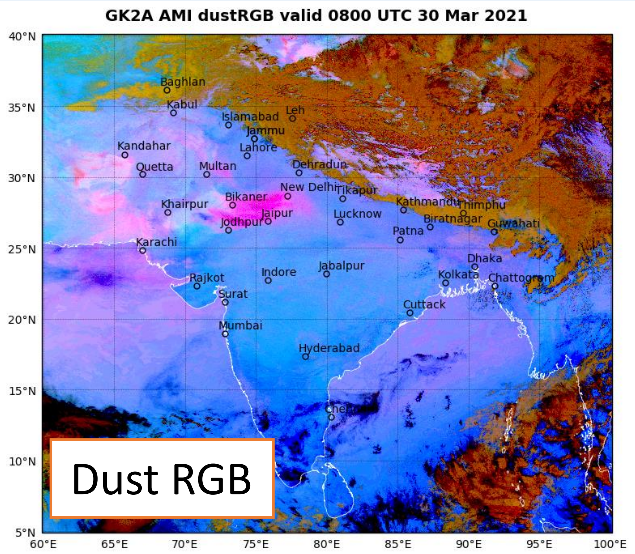


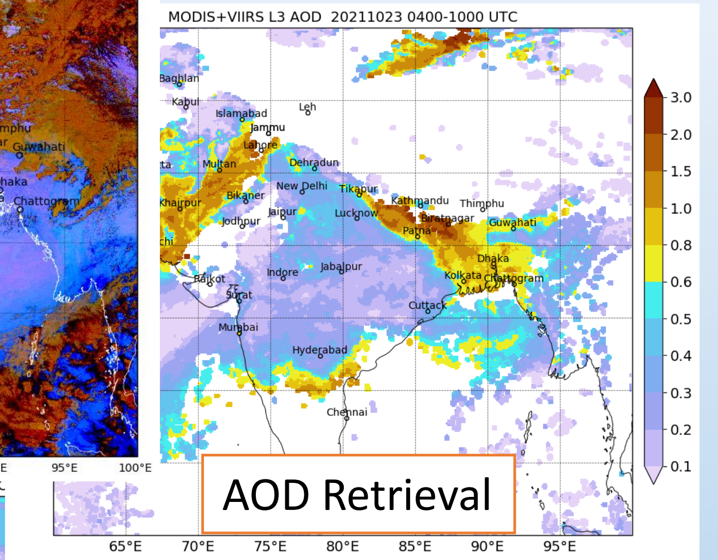



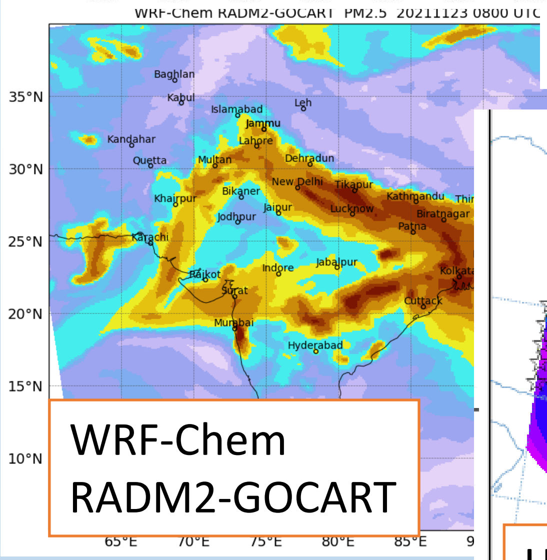

- **Air pollution is a serious threat to human health in HKH, as poor air quality (AQ) is a common occurrence across the region**
- Air pollution is difficult to monitor and predict in HKH due to strong and rapidly evolving emissions
- New generation satellite sensors are capable of significantly advancing AQ monitoring capabilities, especially in areas of highly variable pollution
- New satellite observations are perfectly suited for constraining or assimilating chemical transport models and improving AQ forecasts
- Growing network of ground-based monitors / sensors for complementing satellite & model data

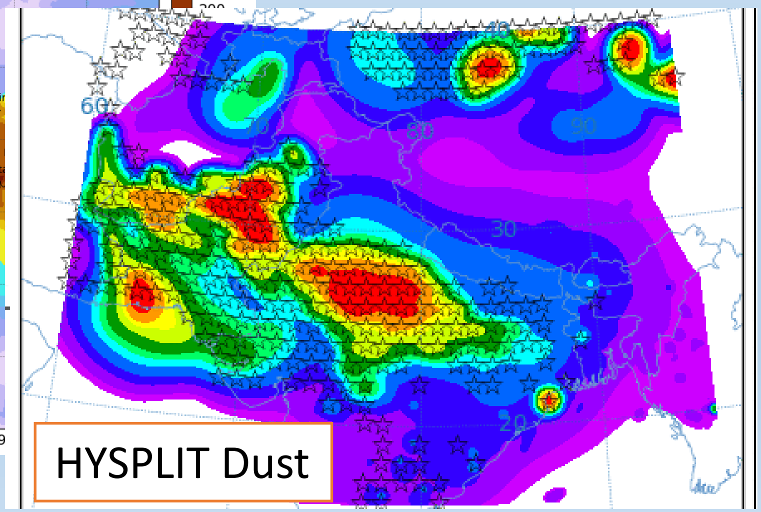
# Foundational Products and Tools

1. Suite of Red-Green-Blue (RGB) products from the GK2A Advanced Meteorological Instrument (AMI) for **monitoring diurnal evolution of dust, fires, smoke and fog**
2. High-level (L2+) trace gas and aerosol products developed from composite satellite and model data to **track air pollution in the troposphere and surface layer**
3. WRF_Chem transport model for **accurately predicting AQ** in the HKH region and **providing timely warnings to the public**
4. HYSPLIT dispersion model for efficiently **predicting dust pollution concentrations and enabling rapid response to dust storms**



# GEO Channel Comparison for RGB Products

- We apply RGB recipes to GK2A/AMI for air-quality-related products
- GEO-KOMPSAT-2A (GK2A)/AMI vs. GEOS-R/ABI, and Himawari/AHI:
  - ✓AMI and AHI have Visible-Green channel at 0.51 micron

    **<u>Benefit</u>: No need to infer VIS-Green for affected RGBs, as in GOES-16/17/ABI**
  - ✓AMI does NOT have 2.3-micron SWIR

    **<u>Drawback</u>: Diminished ability to discriminate cloud particle size & fire hotspot intensities**

| Channel No | Channel | AMI (μm) GK2A | ABI (μm) GOES-R | AHI (μm) Himawari |
|---|---|---|---|---|
| 1 | VIS (blue) | 0.470 | 0.470 | 0.46 |
| 2 | VIS (green) | 0.511 | | 0.51 |
| 3 | VIS (red) | 0.640 | 0.640 | 0.64 |
| 4 | VNIR | 0.865 | 0.865 | 0.86 |
| 5 | SWIR | 1.380 | 1.378 | |
| 6 | SWIR | 1.610 | 1.610 | 1.6 |
| | (SWIR) | | 2.250 | 2.3 |
| 7 | MWIR | 3.830 | 3.90 | 3.9 |
| 8 | MWIR (WV) | 6.241 | 6.185 | 6.2 |
| 9 | MWIR (WV) | 6.952 | 6.95 | 7.0 |
| 10 | MWIR (WV) | 7.344 | 7.34 | 7.3 |
| 11 | TIR | 8.592 | 8.50 | 8.6 |
| 12 | TIR | 9.625 | 9.61 | 9.6 |
| 13 | TIR | 10.403 | 10.35 | 10.4 |
| 14 | TIR | 11.212 | 11.20 | 11.2 |
| 15 | TIR | 12.364 | 12.30 | 12.3 |

# General Formulae for RGB Imagery

$$Red = \left(\frac{R - R_{min}}{R_{max} - R_{min}}\right)^{1/\gamma}$$

$$Green = \left(\frac{G - G_{min}}{G_{max} - G_{min}}\right)^{1/\gamma}$$

$$Blue = \left(\frac{B - B_{min}}{B_{max} - B_{min}}\right)^{1/\gamma}$$

Where:

- *R, G,* or *B* is the present pixel value
- *min* and *max* are the calibrated thresholds applied to a given channel or channel difference
- $1/\gamma$ is the calibrated power scale to affect the color stretching

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Red* | *Green* | *Blue* | *Gamma* | *Applications* |
|---|---|---|---|---|---|
| **Dust RGB** | $IR_{12.3} – IR_{10.5}$ (-6.7 to +2.6C) | $IR_{11.2} – IR_{8.7}$ (-0.5 to +20C) | $IR_{10.5}$ (-11.95 to +15.55C) | 1.0 (RB) 2.5 (G) | **Dust plume monitoring** |
| **Nighttime Microphysics** | $IR_{12.3} – IR_{10.5}$ (-6.7 to +2.6C) | $IR_{10.5} – SW_{3.8}$ (-3.1 and +5.2C) | $IR_{10.5}$ (-29.55 to +19.45C) | 1.0 | **Fog, smog, and low-cloud detection** |
| **Truecolor RGB** | $VIS_{0.64}$ (0 to 1.0 refl) | $VIS_{0.51}$ (0 to 1.0 refl) | $VIS_{0.47}$ (0 to 1.0 refl) | 2.2 | **Land surface, clouds and smoke** |
| **Natural Color Fire RGB** | $SW_{3.8}$ (0 to 60C) | $VIS_{0.87}$ (0 to 1.0 refl) | $VIS_{0.64}$ (0 to 1.0 refl) | 0.4 (R) 1.0 (GB) | **Fire hot spots [and smoke]** |
| **Fire hot spot detection (GEO + LEO)** | **AMI channels combined with** land type, sfc temp, and **MODIS/VIIRS** to identify fire locations at **hourly frequency** | | | | **Fires; early warning on smoke hazards** |
| **Hourly Composite AOD** | Uses suite of AMI VIS and IR channels to provide high-quality depiction of total-columnar atmospheric aerosols | | | | **air pollution / data assimilation** |
| **Hourly Composite $PM_{2.5}$** | Surface $PM_{2.5}$ **derived from hourly AOD and WRF-Chem** with **data assimilation** model output | | | | **Air quality and health** |

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Applications* |
|---|---|
| **Dust RGB** | **Dust plume monitoring** |
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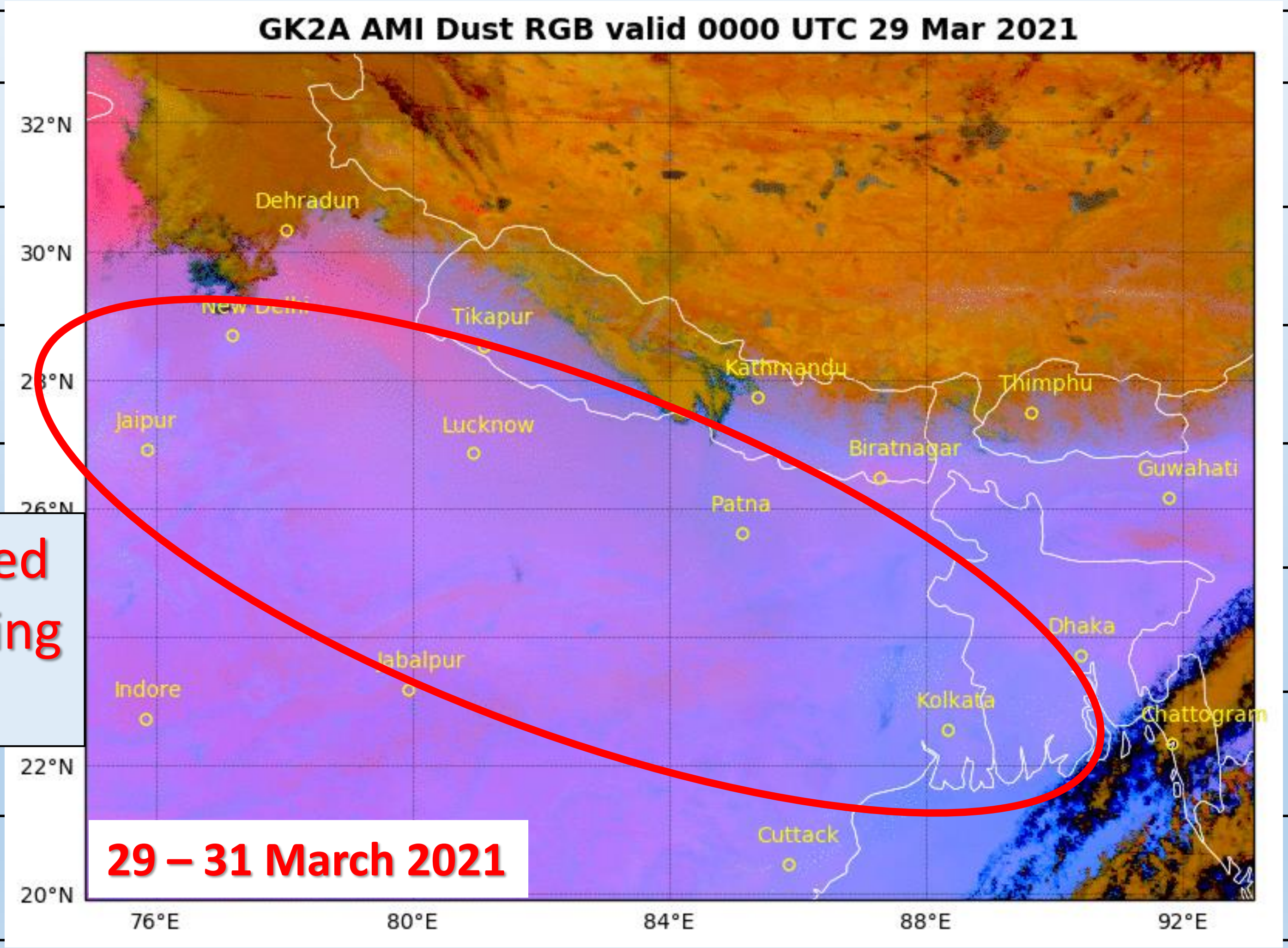


Dust areas denoted by magenta shading (24-h coverage)

**29 – 31 March 2021**

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Applications* |
|---|---|
| | |
| **Nighttime Microphysics RGB** | **Fog, smog, and low-cloud detection** |
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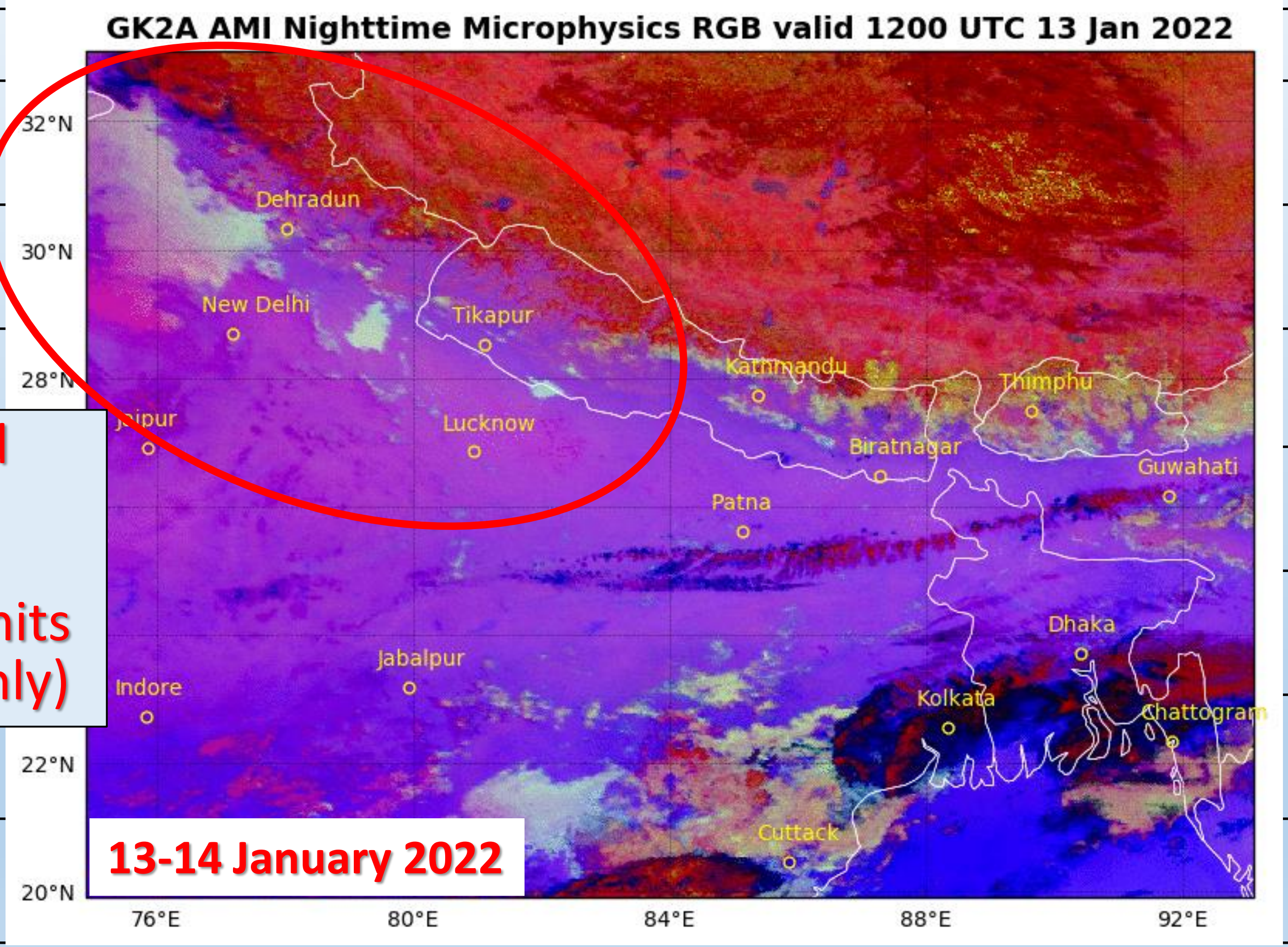
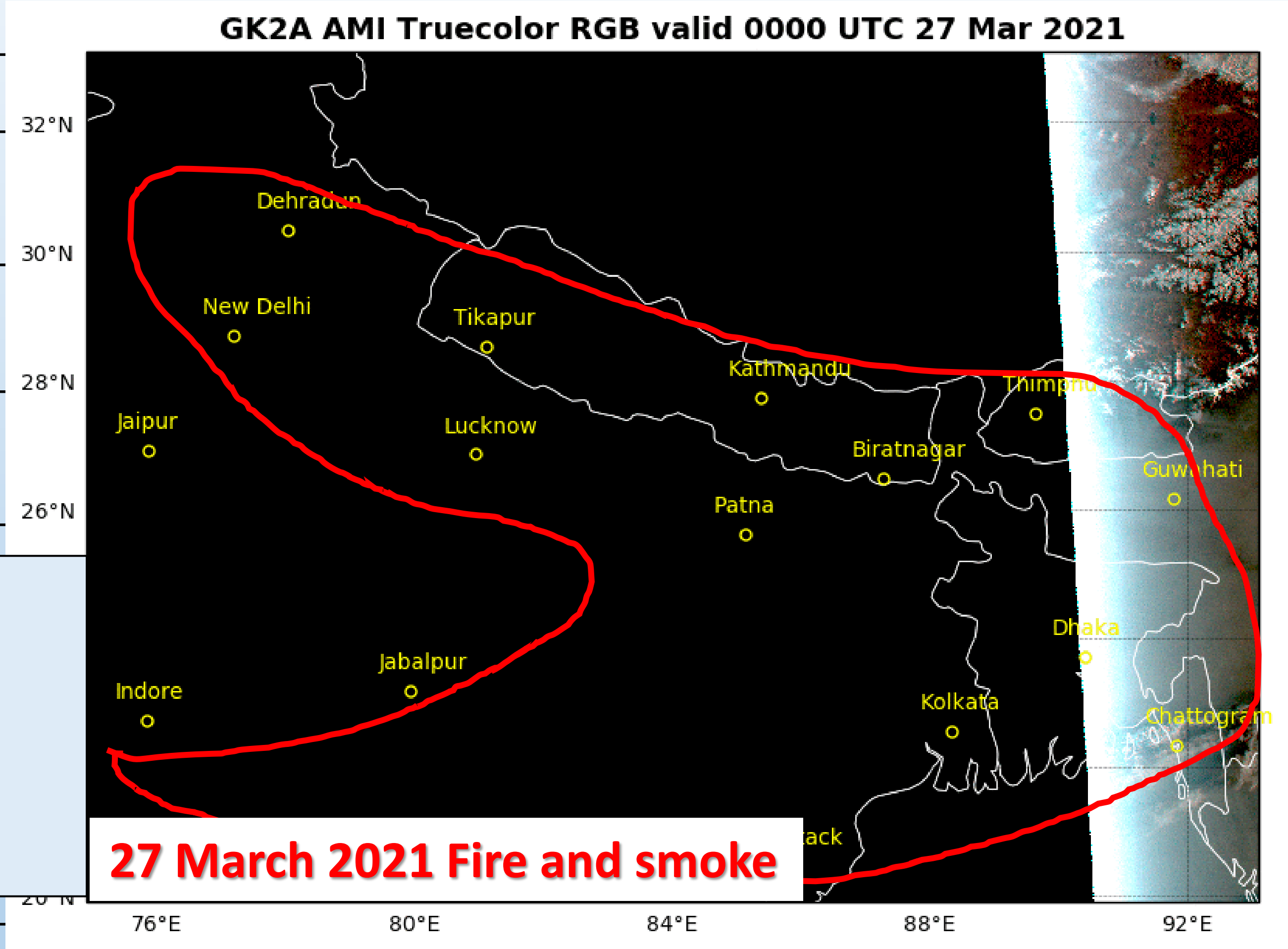



Highlights fog and low clouds. (<u>Limitation</u>: $SW_{3.8}$ contamination limits its use to night-only)

# GK2A-Based Product Suite for AQ Monitoring

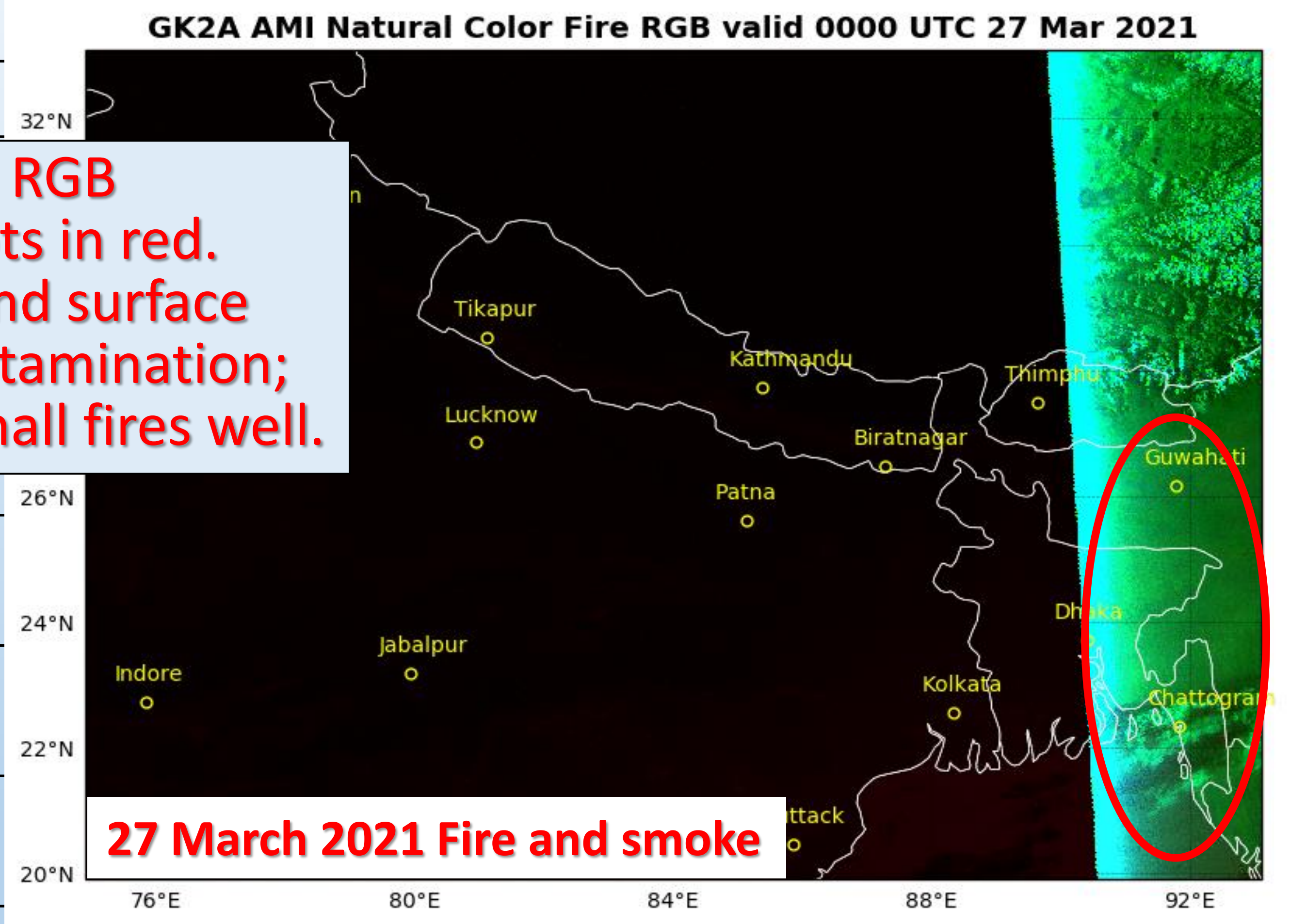



| *Satellite Product* | | *Applications* |
|---|---|---|
| | | |
| | | |
| **Truecolor RGB** | | **Land surface, clouds and smoke** |
| | | |
| | | |
| | | |
| | AMI channels combined with land type and sfc temp to identify fire locations at hourly frequency | **early warning on smoke hazards** |

Truecolor depicts widespread regional smoke / haze from largely prescribed burning. (day only)

# GK2A-Based Product Suite for AQ Monitoring

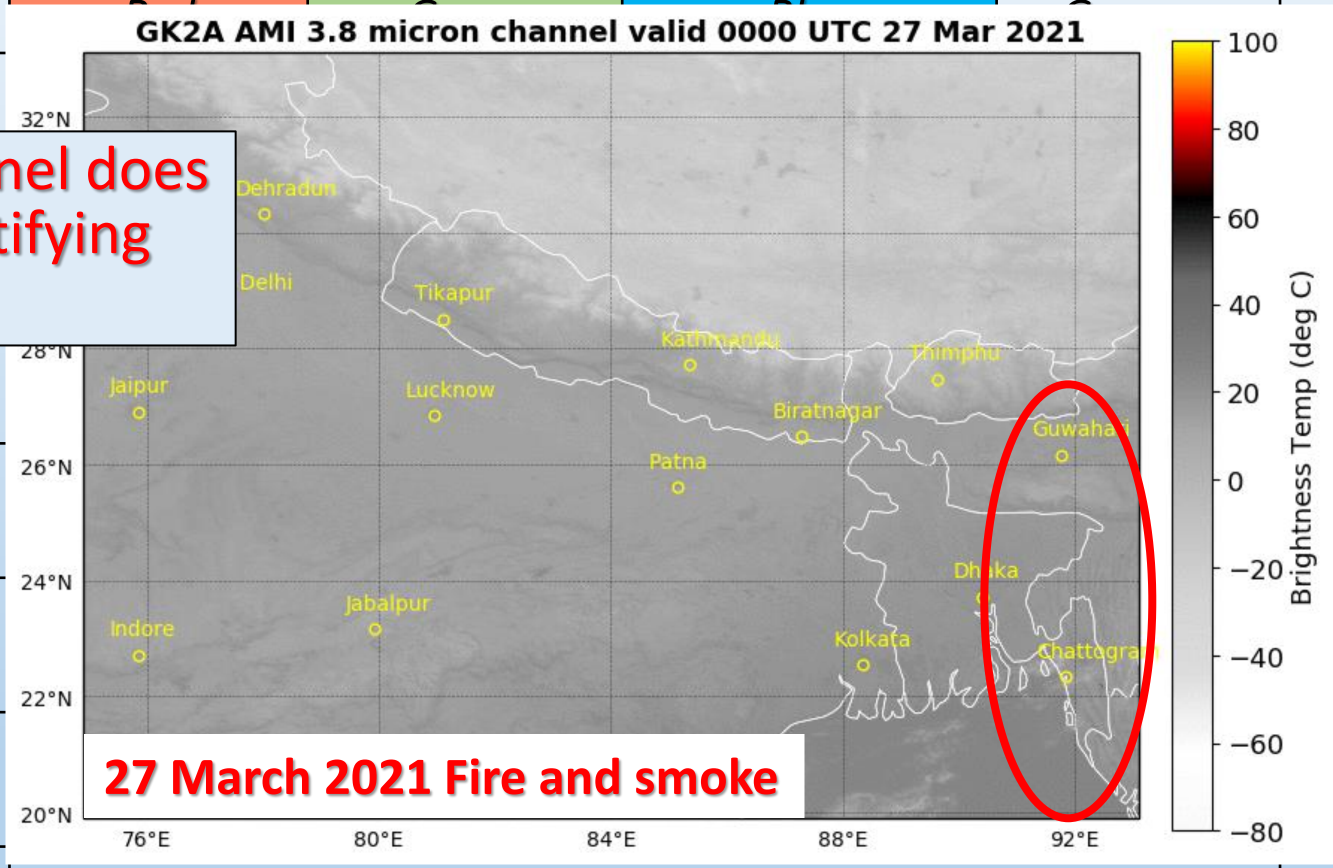
Natural Color Fire RGB highlights hot spots in red.
Limitation: Hot land surface leads to color contamination; Doesn't detect small fires well.




| *Satellite Product* | | *Applications* |
|---|---|---|
| Natural Color Fire RGB | | Fire hot spots |
| | AMI channels combined with land type and sfc temp to identify fire locations at hourly frequency | Fires; early warning on smoke hazards |

# GK2A-Based Product Suite for AQ Monitoring

Simple $SW_{3.8}$ channel does decent job in identifying fire hot spots.




| *Satellite Product* | | | | | *Applications* |
|---|---|---|---|---|---|
| | | | | | |
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| | | | | | |
| **$SW_{3.8}$** | | | | | **Fire hot spots** |
| | | | | | |
| | | | | | |
| | AMI channels combined with land type and sfc temp to identify fire locations at hourly frequency | | | | **Fires; early warning on smoke hazards** |

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Applications* |
|---|---|
| | |
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| | |
| **Fire hot spot detection GEO + LEO** | **Fires; early warning on smoke hazards** |
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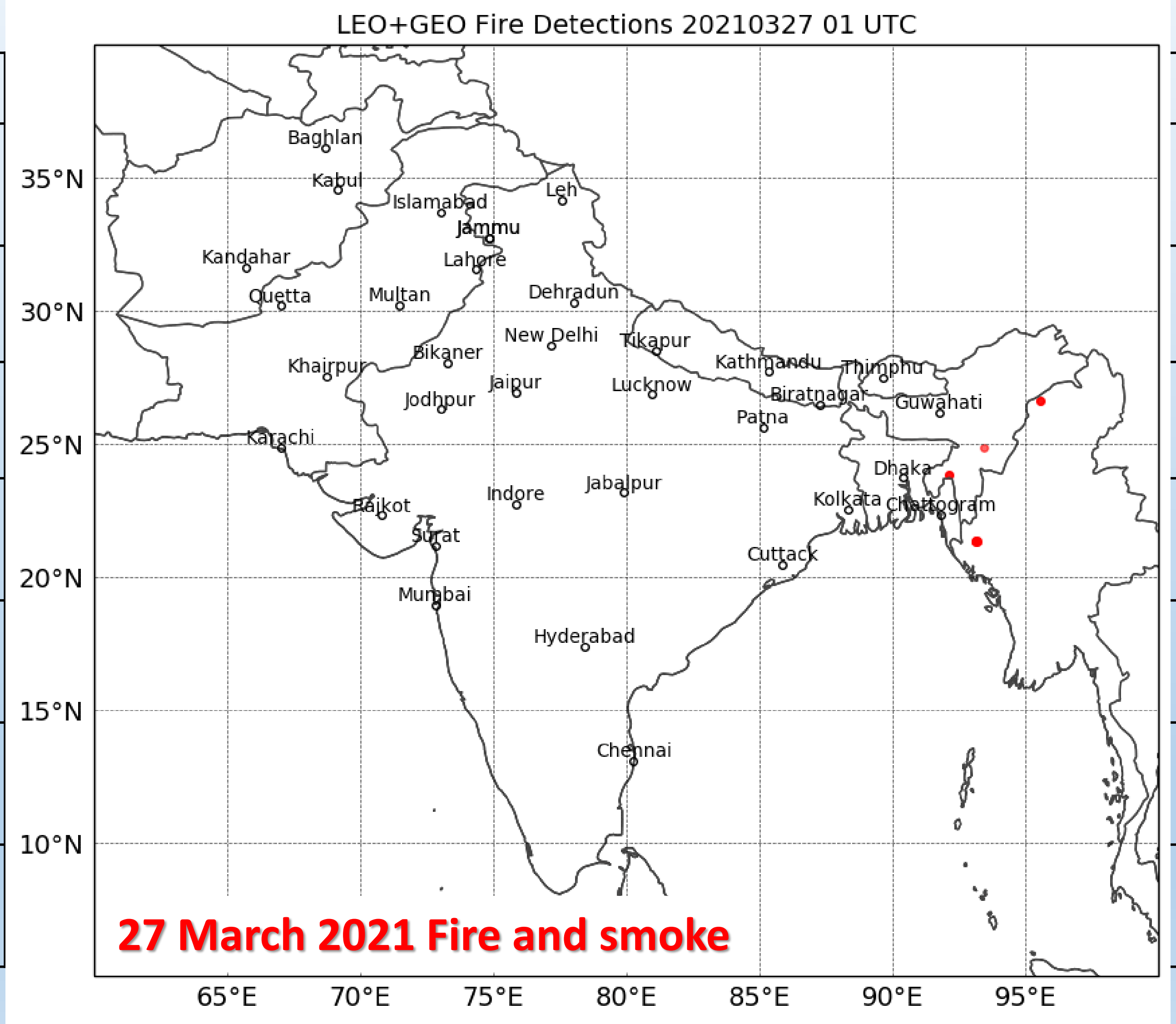

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Applications* |
|---|---|
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| **Hourly Composite AOD** | **air pollution / data assimilation** |
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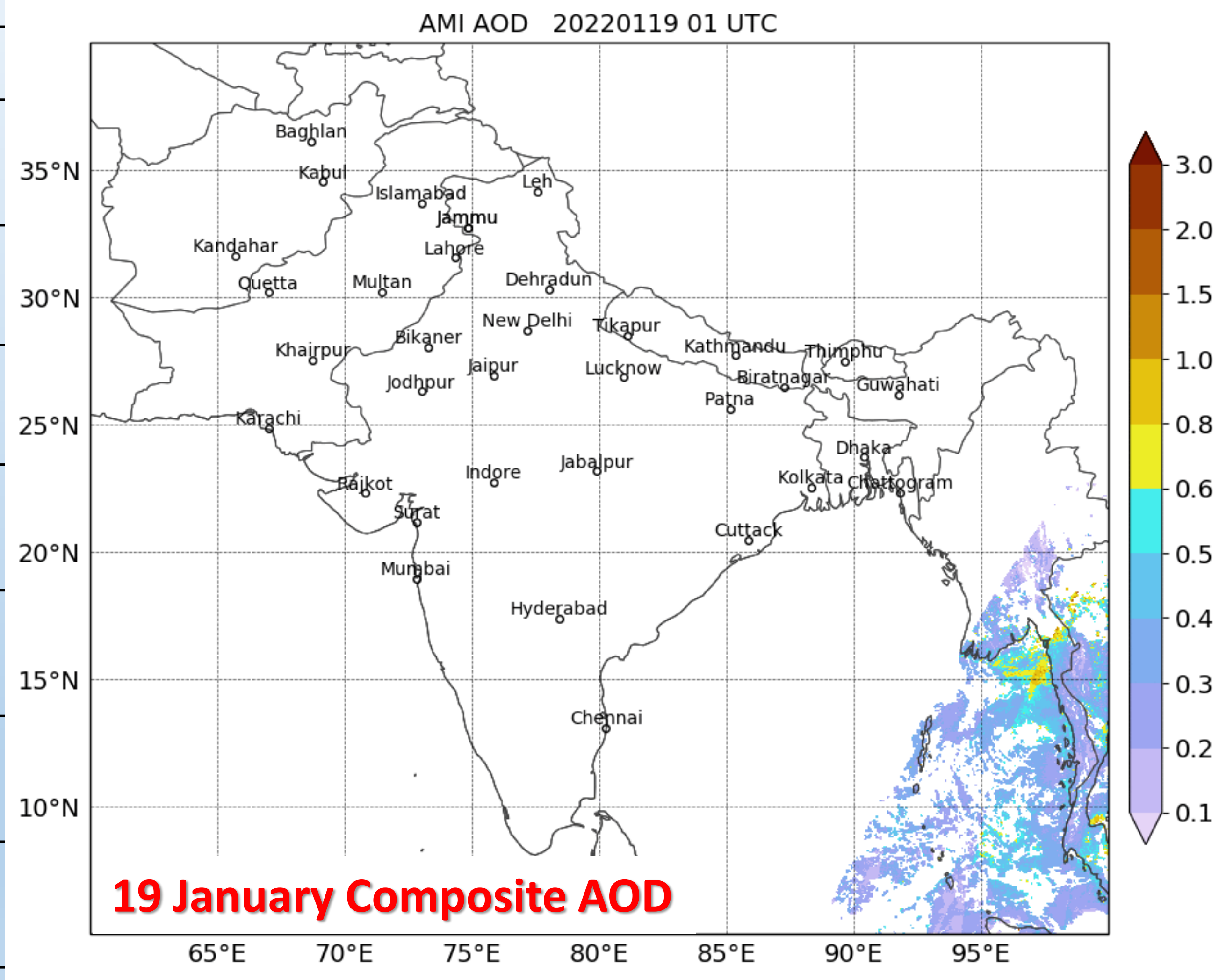

# GK2A-Based Product Suite for AQ Monitoring

| *Satellite Product* | *Applications* |
|---|---|
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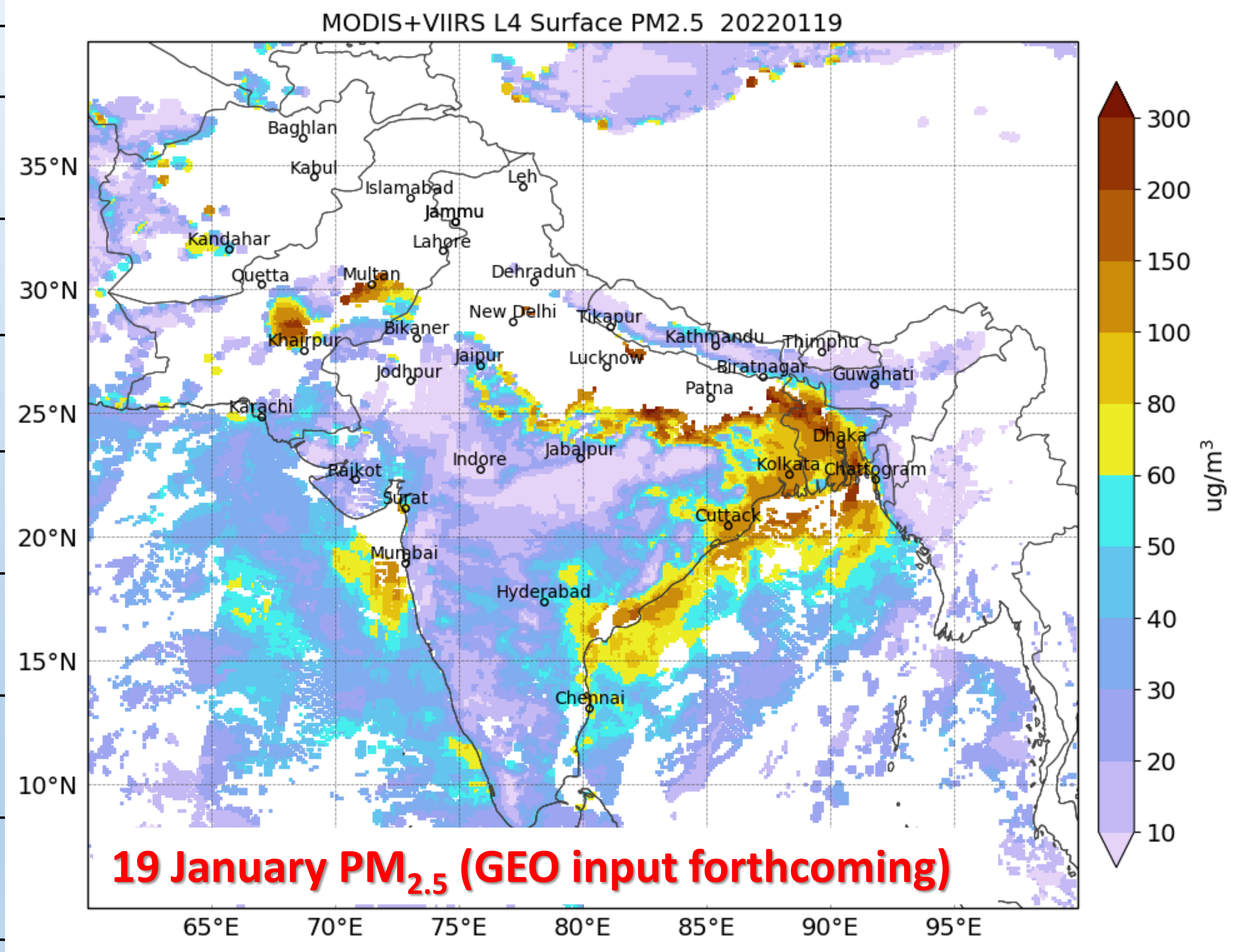
| **Hourly Composite $PM_{2.5}$** | **Air quality and health** |
| | |

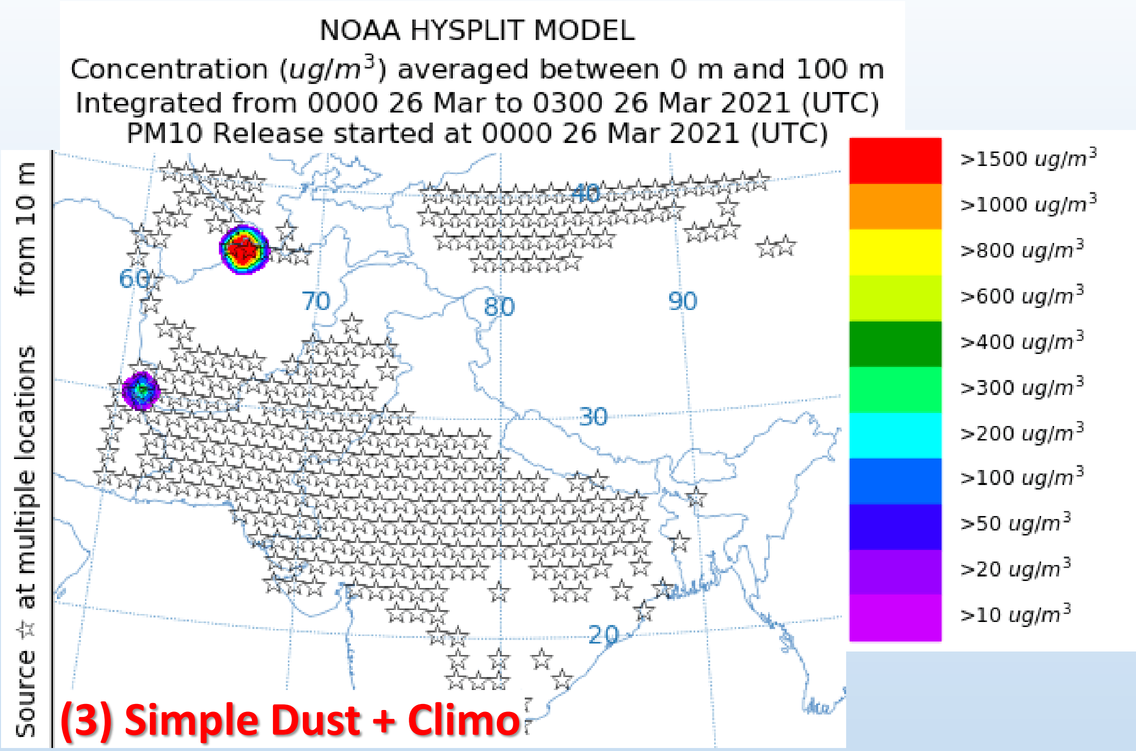


# Late March 2021 Dust Event: HYSPLIT Sensitivity Simulations

- Three method to simulate dust dispersion in HYSPLIT
  1. *Simple dust algorithm:* $Q = 0.01\ U_*^4\ A$ (hard-wired threshold friction velocity, $U_*$, of 28 cm $s^{-1}$ at prescribed desert land-use points, with emission area A)
  2. *Spatiotemporally-varying $U_{*t}$ and emission factor:* $Q = K\ A\ (U_* - U_{*t})$
     - *K A* is the product of soil-dust density *K* and emission area *A*
     - *Monthly climatology database of $U_{*t}$ and K A based on MODIS AOD data (Draxler et al. 2010)*
  3. *Apply monthly climatology emission locations to simple dust algorithm*

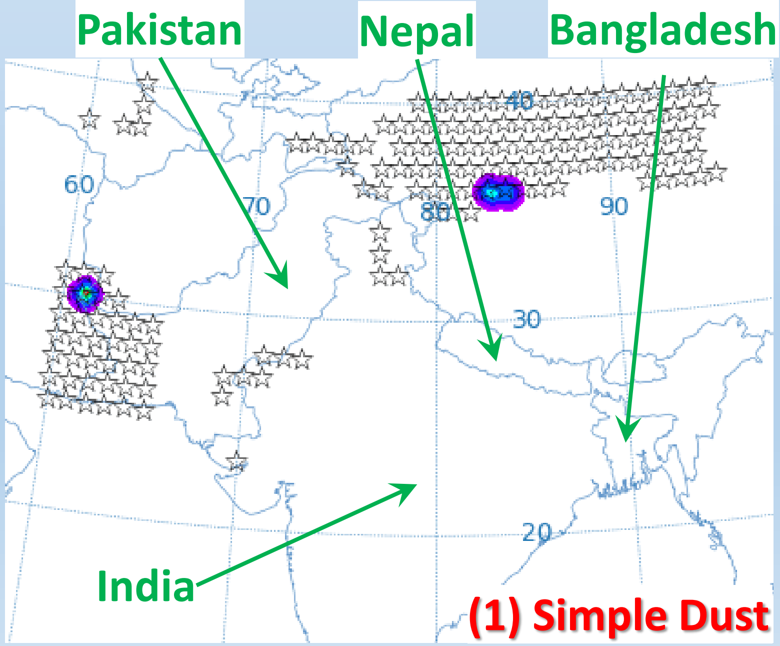
- Six-day simulations spanning 0000 UTC 26 March to 0000 UTC 1 April 2021
- No deposition used initially with these simulations

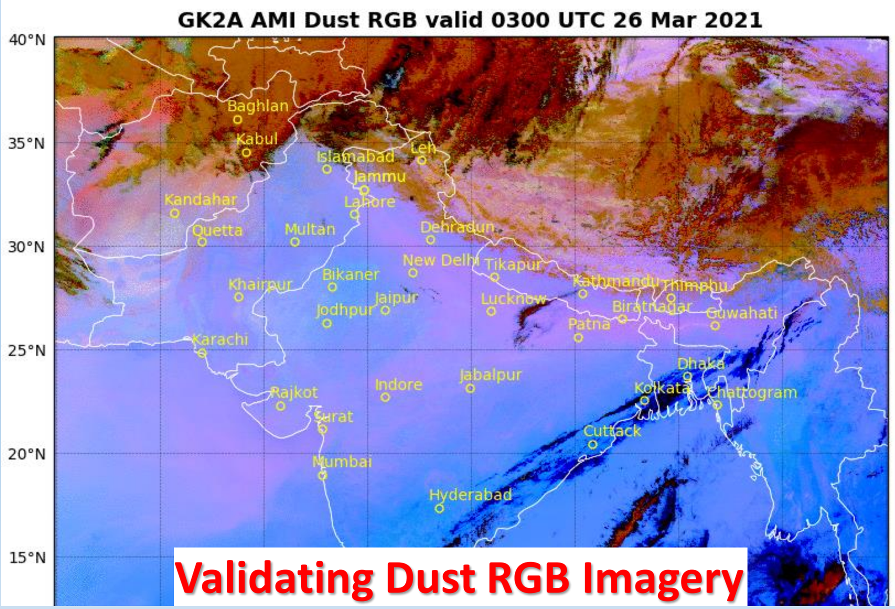
# March 2021 Dust: HYSPLIT Sensitivity Simulations

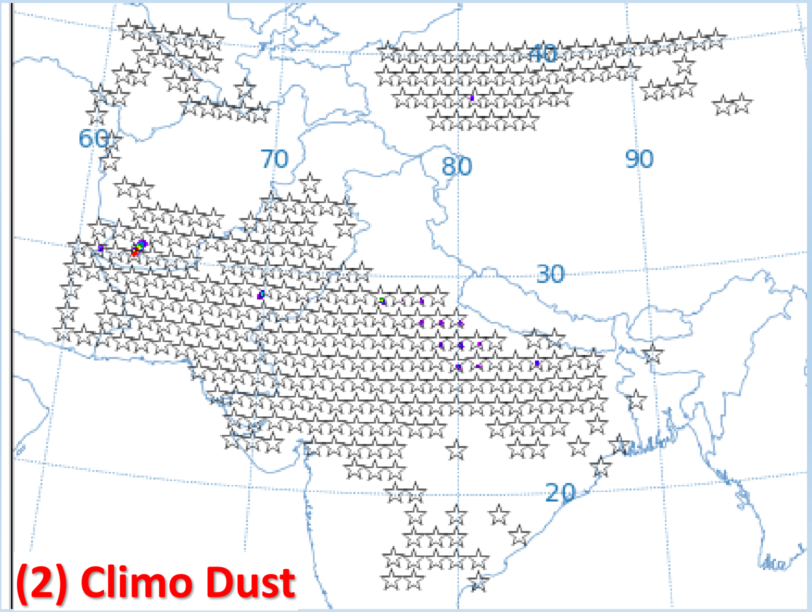



**Some Take-Aways:**

- Simple dust run (1) has far fewer emission locations than March monthly climo (2)
- Despite many more emission points, climo run (2) produces lowest overall concentrations
- Combo of climo points and simple dust algorithm (3; top) generated best overall pattern of high concentrations.



# Summary and Future Direction

- Automate daily HYSPLIT dust simulations over HKH region
- Transition RGB product generation and HYSPLIT simulations to ICIMOD
- Implement WRF-Chem solution into near real-time
- Explore optimized HYSPLIT dust emission initialization
  - ✓ *Location information from Dust RGBs using Berndt et al. (2021) methodology*
  - ✓ *Automate identification method for initializing dust emission*
- Seek to incorporate and implement GEMS satellite products

# Contact Information

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- SERVIR program web site: https://www.servirglobal.net/
- SPoRT program web site: https://weather.msfc.nasa.gov/sport/
- International Centre for Integrated Mountain Development (ICIMOD):

  https://www.icimod.org/ ICIMOD

# (Backup Slides Follow)

# Project Objectives

1. Intelligently **fuse information** from state-of-the-art satellite sensors to develop comprehensive products **for advancing real-time air pollution & fog monitoring capabilities**
2. Design a **tailored chemical transport model framework for providing accurate AQ**, fog/smog, and temperature/stability **forecasts**
3. Apply **lagrangian dispersion model** informed by our tailored products **to aid in the rapid response to extreme AQ/disaster** events
4. **Implement** satellite- and model-based **AQ products into applicable Decision Support Systems**, and develop customized end-user training

## Overarching Project Goal:

**Deliver an advanced air quality monitoring & forecasting toolkit for providing accurate and timely alerts/warnings to the public**